A Kid's Cave
Teaching Earth Science in an Inexpensive Portable Immersive Environment

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Abstract: New technology brings immersive experiences to the student, surrounding him or her in an interactive virtual environment, often beyond direct observation. In this dome CAVE, students can make discoveries as they are made in science visualization laboratories. In like manner, visualizations developed for scientific research can be adapted to create student learning experiences.

I. INTRODUCTION

Modern science takes place in environments and at time scales beyond direct human observation. An urban classroom on Earth is not the best place to observe interactions ranging in scale from solar system bodies to the components of a cell. Often learners are forced to create their own mental images to understand situations they cannot view directly. In many instances the result has been a misconception that takes on a reality of its own inside the student's mind. Standard textbooks and even well designed videos have been shown ineffective in changing these deeply rooted misconceptions [Anderson 1994, Finney 2002]. Students remain confused about topics involving basic spatial relationships such as the reason for the seasons [Schneps & Sadler, 1988]. This challenge is magnified with learners who have limited real world experiences or speak English as a second language.

II. TECHNOLOGICAL SOLUTIONS

Modern computer technology has led to immersive environments that are effective teaching and learning tools for a wide range of learners. With increasingly larger displays, the learner's sense of presence is increased [Lin et al. 2002, Tan et al. 2003]. Increasing the size and field of view for a video increases the sense of enjoyment, involvement, participation [Lombard et al. 2000] and spatial orientation [Tan et al. 2004.] In immersive environments, learners see themselves inside the environment, rather than watching from outside. Research indicates that males outperform females in spatial skills within virtual environments [Sandstrom et al. 1998]. Experiments show, however, that increasing the field of view can remove this gender bias, equalizing male and female performance [Tan et al. 2003].

Use of immersive virtual reality (VR) environments is increasing in education and training [Roussou 2004] with the dominant technologies being head-mounted displays and CAVEs [Buxton & Fitsmaurice 1998] and now the digital dome theater [Sumners, 2003]. Head-mounted displays are limited to single users while research indicates that large projection screens can provide an equivalent amount of spatial recognition [Patrick et al. 2000].

CAVEs (CAVE Automatic Virtual Environments) [Cruz-Neira, Sandin & DeFantin, 1993] are rooms where some or all of the walls are computer projections of a virtual environment ranging from oil reserves in seismic data and components of a space station to molecular bonding and organs of the human body. Students face similar challenges in conceptualizing problems they must solve in middle and high school science courses. Yet CAVEs reach only a few learners at a time and are currently prohibitively expensive for use in schools.

In 1998, the immersive dome video theater became another viable virtual reality environment for education. That year,the Houston Museum of Natural Science

Fig. 1. Students attending a program in a portable dome CAVE

(www.hmns.org) opened the nation's first dome video theater in its Burke Baker Planetarium. Independent evaluations of student learning in this theater [Sumners, 2003; Sumners & Reiff, 2004] indicate that the immersive experiences created by full-dome video enhance learning – especially of difficult concepts requiring students to change reference frames.

III. EFFECTIVENESS OF IMMERSIVE THEATER

A random sample of 500 fourth grade students from the Houston Independent School District (HISD: www.houston-isd.org) participated in a research study designed to evaluate the effectiveness of the immersive planetarium experience. Students attended a 45 minute planetarium program where audience interaction is encouraged and moving immersive experiences illustrate concepts. The t-test for paired yielded a t (19.39) that was statistically significant ($p<.001$). In addition, the analysis yielded an effect size (+1.27) that suggests that the gains made by students from the pretest to the posttest were both statistically significant and educationally meaningful. In addition, the results indicate that the number of correct responses for the twenty-two items on the posttest was greater than the number of correct responses for all but two of the twenty-two items on the pretest. These results suggest that the Planetarium was also effective in increasing student science achievement.

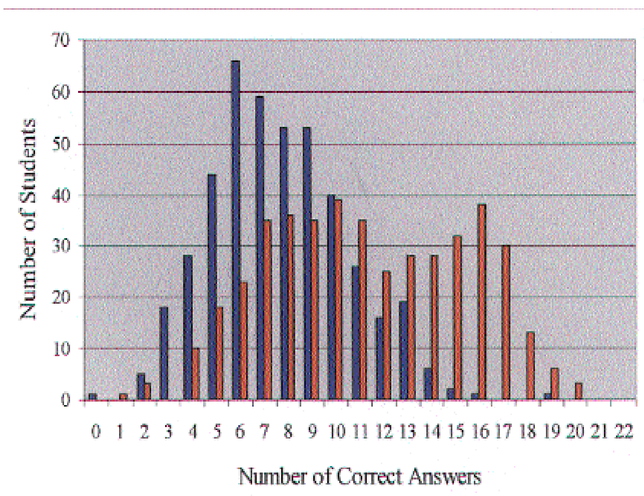

Fig. 2. Pretest (blue) and Posttest (red) scores of students in the fourth grade planetarium field study

The planetarium test was divided into three subscales:
a. Concepts taught primarily through words and non-moving 2D visuals
b. Concepts taught primarily through moving 2D visuals
c. Concepts taught primarily through immersive visuals

The concepts illustrated with immersive experiences are the ones that are less familiar and more difficult to teach in the classroom. The gain score from pre to post test was greatest for those concepts that were illustrated with immersive experiences. This result was predicted and researchers hypothesize that it is due to the strength of the animations and the engaging nature of the immersive experiences. A field study, addressing this hypothesis, is on-going at the time of paper submission and its results will be added to the final report.

IV. INVENTION OF THE DOME CAVE

Utilization of this virtual reality learning experience, however, has been limited to planetariums with this full-dome projetion technology (approximately 50 in the world).

In 2004, the immersive virtual reality experience became affordable at the school level as HMNS and The Rice Space Institute (RSI, http://space.rice.edu/hmns/) at Rice University invented the portable digital theater or dome CAVE. This inflatable dome contains a computer and projector with a fish-eye lens and reproduces the effective immersive experiences of the large dome theater in a more intimate and interactive setting. The inflatable dome has a hemispherical interior projection screen and an air lock for students to enter. Visitors to the portable digital theater at Burke Baker Planetarium confirm that the immersive experience is identical but immersive feeling is stronger in the smaller dome CAVE.

Fig.3. Visitors lining up for a program in the portable dome CAVE

Over 7,000 students have experienced the portable digital theater in its first year of operation. Seven portable dome CAVES are now in operation around the nation as part of a newly formed consortium. School districts can purchase a complete digital dome theater for under $35,000, including VR visualizations. Now the most complex and expensive virtual environments produced for large dome theaters can reach the most rural and impoverished community of learners.

The portable dome CAVE is an appropriate instructional experience for all grades and achievement levels, but it most benefits those students who are facing the greatest challenges in visualizing complex relationships – especially relationships that cannot be observed directly. The dome CAVE provides a new immersive way to learn. Teachers can start and stop simulations animations and even zoom in on details to discuss an environment or analyze an action. This is most valuable for students whose direct experiences are most limited or whose lack of English proficiency puts them at a disadvantage in a verbal lecturing environment. The dome CAVE teaches with a minimum of words and a maximum of visual stimulation and interaction. The dome CAVE is also very different from the classroom experience. It is far more engaging and completely immersive. It controls the student's visual world and by definition removes common distractions that limit student attention in a classroom. The dome CAVE lets 30 students share a full-dome "computer screen" that changes all around them.

V. DEVELOPMENT OF ANIMATIONS

Because of HMNS's five years of digital production, following immersive experiences are already available for the dome CAVE as listed in Table A. These experiences are created by a 3D animation package (3D Studio Max, Bryce, LightWave, or Maya), rendering the sides and top of a cube, and stitching the individual frames into a hemispherical fisheye image. These images are converted into digital moves that fill the dome CAVE.

Fig.4. Maya Fisheye Animation of a *Tyrannosaurus rex*

In the last year, HMNS and RSI have also perfected the technique of capturing environments with a fisheye lens high-resolution camera and transforming them into immersive full-dome scenes. This technique allows untrained teachers to participate in the photography for full-dome programs. Through creation of buttons in the media player interface, teachers can immediately project their full-dome images and begin using them in student programs.

All of these experiences are places that students cannot or should not observe directly. For instance, in a dome CAVE, students can experience a tornado complete with sounds, rain, hail and a twister setting down in front of the audience. Through their observations, they can describe the events leading up to the storm and the storm's power without leaving the safety of their school. Teachers can also stop the action to observe and record data during the event.

Earth Events	**Space Travel**	**Historical Simulation**
Woolly Mammoths	Inside observatories	Big Bang
Dinosaurs w/ impact	Planet orbits	Galileo's study
Volcanic Eruptions	Through Saturn's rings	Stonehenge
Hurricane at sea	Space Station	Egyptian pyramids
Ice Age animation	Future moon landing	Sinking of Titanic
Tornado on land	Animated alien worlds	Apollo Mission Control
Extremophile locations	Coronal mass ejection	Petra/Jerusalem
Dead Sea Formation	Moon phases/eclipses	Birth of moon

Table A: Immersive Dome CAVE Experience

Finally, in the summer of 2004, HMNS and Rice University offered a course in training teachers to operate the portable digital theater system. Thirty-eight teachers from HISD were admitted into the course with a long waiting list. HISD's Urban Systemic Initiative funded the participation of these teachers. Thirty of these teachers demonstrated that they could operate the system effectively after a week of instruction. Some of these teachers now take the portable dome theater to schools and community events in six states with funding from a NASA Broker Facilitator grant to HMNS. The immersive portable dome CAVE is a viable and easily used educational environment that can bring immersive interactive experiences to all students.

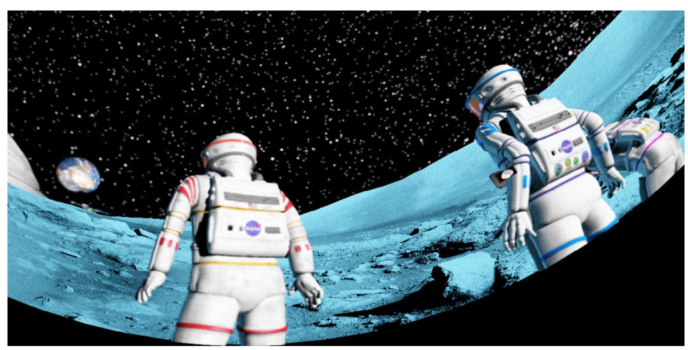

Fig.5. Students born on the moon watch the moon's shadow crossing Earth during a total solar eclipse.

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